

**PJP/2009/FKP (11A) S579**

**POTENTIAL APPLICATION OF BIODEGRADABLE TS/SCFC GREEN  
COMPOSITE FOR DISPOSABLE PACKAGING FOOD CONTAINER**

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**REPORT ORGANIZATION**

This report consists of two parts which contributed to the main research topic. Part 1 is reporting on the “Potential application of Tapioca Starch / Sugar Cane Fiber Cellulose Green Composite for Disposable Packaging Food Container” and Part 2 is reporting on the “Innovative Thermoplastic starch Based Biodegradable Packaging for Food Industries Application”.

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## PART 1

### *Potential Application of Tapioca Starch / Sugar Cane Fiber Cellulose Green Composite for Disposable Packaging food Container*

#### ABSTRACT

The noble aim of this research is to investigate extensively the potential application of Tapioca Starch (TS) filled Sugar Cane Fiber Cellulose (SCFC) biocomposites for disposable packaging food container. This research was started by preparing and characterizing the SCFC through various characterization tools. The effect of the optimum SCFC loading to the fabricated TS composites was studied as to establish the best formulation of the TS/SCFC biocomposites. The thin sheet of composite samples were then fabricated with different blend formulation via compression molding machine and the samples were cut into the specific dimension, according to the ASTM standard for each different testing. Further testing for various engineering properties of TS/SCFC biocomposites were carried out, such as tensile test, impact test, flexural test and hardness test. These tests were used to determine the mechanical properties of the fabricated composites. Then, it was followed by conducting the physical test such as weathering test, water absorption test and the thickness swelling test. Other than that, the Fourier Transform Infrared (FTIR) analysis was conducted as to investigate the degradation behavior of the biocomposites. In order to observe the fracture morphology of the samples, the optical microscope was utilized comprehensively. Generally, the results of this study have shown good performance for both the mechanical and physical properties of the fabricated composites. However, through the morphological observation on the mechanical and physical testing fractured surfaces, it was clearly found that the adhesion between the SCFC and TS matrix were not well attached. This study has indicated the role of fiber loading into the resulted properties of the fabricated composites. Development of this alternative container material for food packaging application will provide a great potential solution to the environmental friendly and safe packaging medium either for food, consumer or environment as a whole.

#### INTRODUCTION

Plastics due to their versatility are making great in the field of packaging of a variety products such as processed and convenience foods, pharmaceuticals and medicines, cosmetics and toiletries, household and agricultural chemicals, petroleum products and detergent and etc. As we know, plastic containers have actually succeeded in replacing metal, glass, tin, aluminum and paper containers in many applications. The advantages of plastics are light and less bulky than other packaging materials, can be processed into any desired shape or form such as films, sheets and pouches, it save costs of storage and transportation because of lower volume, easy for coloring, no rusting and good water resistance. Although plastic package have tremendous advantages, they have been some limitations that includes some chemical attack on particular plastics, less heat resistance, tendency to creep, lower gas barrier and lower dimensional stability (Kadoya, 1990; Athalye, 1992).

In addition, there are serious problems connected with the analytical control of such materials; toxic hazards from the modified plastics and also from their degradation products, increased costs and the possible encouragement of litter (including non plastics component). In order to reduce this problem, the application of using biodegradable material is an alternative method. Biodegradable which are often produced from renewable sources, are being increasingly sought after by food processors as part of a solution to environmental concerns over waste and the use of fossil fuels. The process is called biodegradation (Dong *et al.* 2008). Biodegradation is a natural process by which organic chemicals in the environment

are converted to simpler compounds, mineralized, and redistributed through the elemental cycles such as the carbon, nitrogen, and sulphur cycles through the action of naturally occurring microorganism.

In this research, biodegradable polymer matrix composites were developed. There are two natural components will be combined in the fabrication of innovative biocomposites for the application of food packaging. One is a natural biofiber utilizing sugar cane fiber cellulose (SCFC) while the other is biodegradable matrix material which is tapioca starch (TS). Sugar cane has played an important role in enhancing the composites performance as filler reinforcement. In addition, it was combined with tapioca starch that acts as matrix which has many advantages to the environment. It is anticipated that the development of this product, was contribute to the world as novel biodegradable, non-toxic and non-allergenic bio environmental friendly natural green products.

Nevertheless, there is considerable interest and noble aims in this research where to produce an alternative material by compounding tapioca starch and sugar cane fiber cellulose to replace the existing non biodegradable plastic material in the market. Thus, in overall, this research formulated the biopolymer based composites filled with an agro-waste biofiller by using the internal mixer compounding method in order to investigate and understand the behavior, mechanism and kinetic of degradation for the TS/SCFC biocomposites.

### **Problem Statement (Part 1)**

Great attentions are focused on the utilization of the natural plant fibers to replace the synthetic fibers in the development of polymeric based composites materials. This is due to the advantages of renewability, low density and high specific strength as well as biodegradable and recyclable at the very reasonable cost (Ochi, 2008). These fibers outstanding properties such as high specific strength and stiffness, impact resistance, flexibility, and modulus make them an attractive alternative over the traditional materials (Sgriecia *et al.* 2008). Specifically, good properties of sugar cane fiber cellulose includes good specific strengths and modulus, economical viability, low density and low weight has make them as a promising reinforcement of choice by the industry. Thus, natural fiber like sugarcane can be used as a replacement to the conventional fiber, since the global environmental issues have led renews interest in the development of bio-based materials (Chen and Chung, 1993).

It is important and possible to produce a new types of material that exhibit the economically and environmental friendly benefits for packaging applications in food packaging industries. By combining two different resources, it is possible to blend, mix or process the natural fiber with other elements such as plastics or synthetics material to produce new classes of materials. The important things is to ensure that the fabrication are employed in the controlled temperature processing, because the degradation of the sugarcane will lead to the failure or poor performance to the properties of the fabricated composites (Hanlon *et al.* 1998). Therefore, the selection of suitable processing temperature is crucially important consideration especially when dealing with the fabrication of heat sensitive biopolymer of TS / SCFC green composites. Thus, in this research, study on the effects of the processing parameter to the final properties of the fabricated composites, will be the major focused. The potential of the composites produced to be naturally degraded will be tested, understand and studied comprehensively.

### **Objectives (Part 1)**

The purposes of this study are:

- 1.3.1 To formulate biopolymer based composites filled with agro-waste biofiller by using an internal mixer compounding method.

- 1.3.2 To establish the mechanical, physical and morphological data observation for the novel fabricated TS / SCFC biocomposites in comparisons to the other biocomposites.

### **Hypotheses (Part 1)**

- 1.4.1 The contents of fiber loading or proportion of SCFC used of this study will affect the final properties of the fabricated composites. It is expected that, by increasing the proportion of fiber loading, the properties of the fabricated composite will be increased correspondingly in accordance to the rules of mixture (RoM) theory.
- 1.4.2 Introduction of biopolymer in this study will increase the final properties of the fabricated composites provided that, good interfacial adhesion formed between the surface interaction of TS / SCFC biocomposites. Thus, it is expected that by increasing the compounding temperature and speed of the roller rotors rotation, it will improves the interfacial adhesion of the composites produced.
- 1.4.3 It is expected that, the biofiller used will further enhanced the rate of degradability of the composites produced. Thus, by increasing the weight percentage or SCFC loading in one matrix of TS, it will accelerate the kinetic in degradation.

### **Importance of Study (Part 1)**

Critically, the noble aim of this research which to develop the green materials for the application of food packaging. Thus, by conducting this research, it is expected that it will be benefited to the environment that suffer with the non-degradable waste of plastic food packaging caused by uncontrolled solid waste disposal and extensive use of this necessity. Development of this novel food packaging alternative will create potential solution to the environmental friendly and safe packaging medium either for food, consumer or environment as a whole.

### **Scope of Study (Part 1)**

Sugar cane fiber cellulose (SCFC), tapioca starch (TS) and glycerol were used in this research as raw materials. The study was started by preparing and characterizing the sugar cane fiber as reinforcement material. The next stage involves the drying study of SCFC. SCFC were dried in the drying oven for several period of time and the weight losses of fibers were determined accordingly. Then, TS, SCFC and glycerol were compounded by using the internal mixer. The effect of optimum filler loading to the fabricated composites will be further studied and the best formulation of composites was suggested. After that, compression molding machine was utilized to prepare the samples. The blend of fiber and matrix were pressed by using the compression molding machine to produce the thin sheet of composites samples. The fabricated composites were cut into the specific dimension according to the ASTM standard for various types of selected testing. The best compounding of TS / SCFC will be determined by one-factor-at-time (OFAT) statistical method. In order to achieve the objectives of this research, further testing analysis for various engineering properties of TS / SCFC were carried out such as tensile test, impact test and flexural test. These tests were used to determine the mechanical properties of the samples. Then, it was followed by the physical test such as weathering test, water absorption test and thickness swelling test. Other than that, the Fourier Transform Infrared (FTIR) was conducted as to investigate the degradation behavior of the composites produced. In order to observe the fracture morphology of the sample, the optical microscope was utilized. Fractured samples from the flexural testing, impact testing and hardness testing were thoroughly viewed.

## **LITERATURE REVIEW**

### **Introduction**

This part presents the literature review that relates to the theories on composites and previous investigations to the SCFC as the reinforcements while TS as matrix in this composite studied. The study on the SCFC and TS engineering properties also has been highlighted. Through this part, various types of properties and related testing will be studied and discussed.

### **Composites**

Composite can be defined as a combination of two or more chemically distinct and insoluble phases with recognizable interfaces. In such a manner, its properties and structural performance are superior to those of the constituents acting independently (Kalpakjian and Schmid, 2006).

Composites consist of two major parts in their constituents which are matrix and reinforcement. According to Matthews and Rawlings (2002), each of materials must exist of more than 5 wt% to be classified as composites material. Theoretically, the purpose of the composites material is to improve combinations of the mechanical characteristics such as stiffness, toughness and resistance behavior at the ambient and high temperature (Callister, 2003).

Composites materials can be classified into three major classifications which are metal matrix composites (MMC), ceramic matrix composites (CMC) and polymer matrix composites (PMC). In this study, PMC becomes as a major topic of the investigation.

### **Polymer Matrix Composites (PMC)**

Polymer matrix composite (PMC) is material consisting of polymer resin as the matrix combined with a fibers as reinforcement. These materials are used in the greatest diversity of composite applications in the largest quantities considering the ease of fabrication and the factor of cheaper cost (Callister, 2003).

Jacobs and Kilduff, (2001) discussed that PMC are much easier to produce than other type of composites independent of the type of polymer (thermoplastic or thermoset). It also adopts flat, gently curved, or sharply sculpted contours with ease, providing manufacturers with design flexibility. In addition, it is a lightweight material compare to steel, aluminum, and traditional materials such as wood. Besides that, these types of composites can be produced without the need for high curing temperatures or pressures. The product produced has a good balance of properties and high corrosion resistance. The combination of the fiber loadings, will give double strength and stiffness to the plastic resin. Continuous fibers will increase these properties with accompanying desirable decrease in thermal expansion and creep rate and with increase in impact strength, heat deflection temperatures and dimensional stability (Jacobs and Kilduff, 2001).

Nevertheless, there were disadvantages of PMC which need to be considered, such as their low maximum working temperatures, high coefficient of thermal expansion, dimensional instability, and sensitivity to radiation and moisture. This leads to a degree of environmental degradation greater than that experienced by the component material alone. Until early 1970s, the focus was given on the preventing the plastics degradation to avoid the loss in the performance of the plastic properties. The extent of degradation was generally measured by the loss percentages of the useful properties. It was stated that 90 percent loss in tensile strength was equivalent to total degradation, as this was sufficient to render the plastic object unusable. In the middle of 1980s, when concern about solid waste disposal increased, interest

in biodegradation intensified as some perceived it as a solution to the landfill crisis (Hanlon *et al.* 1998; Selke *et al.* 2004; Harper, 2006). Since nearly all the synthetics plastics are not biodegradable, the biodegradation and other types of degradation were proposed (Jacobs and Kilduff, 2001; Harper, 2006).

Thus, this problem on PMC material brought the initial generation and the development of biodegradable material, which most often the mixtures of starch with various thermoplastics (Harper, 2006). Therefore, composites by combining natural fiber and natural biopolymer could be expected as fully biodegradable materials. Thus, this research will gives more focuses to the development of the biocomposites of tapioca starch or reinforced by sugar cane fiber cellulose.

### **Matrix**

Selection of correct matrix material is a must in a way to ensure the efficiency of reinforcement effects introduced by the filler in any composite engineering materials. Matrix can be defined as a constituent in composite material that is in continuous phase and is often but not always present in the greater quantity. This matrix is required to perform several functions, most of which are vital to the satisfactory performance of the composite. The roles of matrix in fiber reinforced and particles reinforced composites are quite different. The binder for particles aggregate simply serve to retain the composites mass in a solid form but the matrix in a fiber reinforced perform a variety of other functions which characterize the behavior of the composite (Callister, 2003).

Matrix binds the fibers together and holding them aligned in the important stress direction. Loads are applied to the composite and are then transferred into the fibers, which constitute the principal load bearing component through the matrix, enabling the composite to withstand compression, flexural and shear forces as well as tensile loads. The ability of composites reinforced with short or chopped fibers is exclusively dependent on the presence of matrix as a load transfer medium. The efficiency of this transfer depends on the quality of the fiber-matrix bond (Jacobs and Kilduff, 2001; Callister, 2003).

The composite performance is influenced by the following matrix properties which are elastic constants, yield and ultimate strength under tension, compression or shear failure strain of ductility, fracture toughness, resistance to chemicals and moisture as well as the thermal and oxidative stability. When selecting a particular matrix for specific composite application, service environment parameters such as temperature stress, moisture, chemical effects and possible radiation damage must be considered (Callister, 2003).

### **Biodegradable Material**

Biodegradable packaging materials may be broadly classified into biodegradable polymers and biopolymers based on the dominating ingredient whether it is synthetic oil-based polymer or a biologically derived polymer. The former are synthetic polymers which either have certain degrees of inherent biodegradability such as polycaprolactone, polyhydroxybutyrate and poly (vinyl alcohol) or chemically modified plastics to assist biodegradation (Bastioli *et al.* 1994; Brody and Marsh, 1997).

Dukalska (2008) stated biopolymers are naturally occurring long-chain molecules. Cellulose, polysaccharides, proteins and DNA are among the common examples. This definition has been extended to materials made or derived from these natural polymers. Unlike synthetic polymer, most of the more biodegradable, i.e. decomposable by biological activity such as through bacteria or fungi will give rise to natural metabolic products. Natural cellulose packaging materials are dominated by traditional corrugated boards' products and molded pulp products, which have been extended in recent years from egg boxes and food trays to solutions in industrial food packaging.



Among commercially available biodegradable packaging materials based on natural raw materials, those based on polysaccharides (starch) are currently the front-runners. This is mainly attributable to the facts that starch is annually renewable and is abundant found around 15 million tones per year which produced in Europe and nearly 50% is used for non-food applications (Löckes, 1998; Jacobs and Kilduff, 2001).

Starch alone is hardly useable as a packaging material mainly due to its poor mechanical properties (brittleness) and its hydrophilic nature. They are often modified mechanically, physically or chemically and or combined with plasticizer or polymeric additives. In combining starch as biodegradable polymer or copolymers; starch content could vary between 50 and 90 wt%. Therefore, it seems to be logical to classify the material as a “starch containing biodegradable polymer” rather than a “starch-based biopolymer”, if the starch content is lower than 50 wt%. For examples, glycerol is always using as a plasticizer that compound with cassava starch, tapioca starch and also potato starch (Petersen *et al.* 1999).

The four major markets for biodegradable materials can be categorized as food packaging, non-food packaging, personal and health care disposal or consumer goods (Nayak, 1999). In addition, performance, process ability and cost consideration are of the major challenges for biodegradable polymers to be cost effective and to fulfill the required functions during the service and disposal life of the product, where hydrocarbon oil-based plastic packaging is to be replaced (Petersen *et al.* 1999). They are also being increasingly researched to replace traditional materials formulated into items such as disposable nappies. It has been suggested that the life-cycle analysis of biopolymer packaging for such single use packaging is more attractive than other alternatives such as paper where both the manufacturing energy and burden of environmental contaminants is higher for paper than polyolefin (McCarthy, 1993; Scott, 2000)

Increasing technological advancement, fuelled by consumer needs for more user-friendly products, is now pushing the polymer markets to find new and novel alternative materials. Evidence of this is plainly visible in the development of biodegradable detergent sachets and clothes washing tabs where the biodegradable polymers end up in the waste water or sewerage system. Currently, higher purchase cost associated with biodegradable polymers remains a constraint to more widespread exploitation of these materials with their application being limited to goods where cost is not the deciding issues. Significant cost reduction is expected with the increase of economy, which at the moment less than 0.1% that of oil-based polymers (Bartle, 2001; Petersen *et al.* 2001; Davis, 2003)

### **Tapioca Starch as Matrix**

According to Industrial Studies and Surveys Division (1980), tapioca or cassava or sometimes called manioc is a hard crop and can grow on any types of soils. Tapioca starch and flour have been used in many literatures. The word flour refers to the powder obtained by grinding the dried tapioca roots. This will consist of starch and fibrous materials almost in equal proportions. In the case of starch it does not include the fibrous material. As such, in proper starch manufacturing, the fibrous material has to be separated and this by product is then sold as animal feed. The starch is a white granular substance with the general formula of  $C_6H_{10}O_5$ . The commercially important ones are starches of maize, tapioca, potato, sago, waxy maize, wheat, sorghum, rice and arrow root. Starches from different plants differ in their granular structure and their physical properties are listed in Table 2.1a showing starch content, moisture content, pH, pulp, ash, and viscosity. These are important parameters as a major technical specification for tapioca starch.



**Table 2.1a:** Specifications for tapioca starch by Thai Tapioca Flour Industry Trade Association, Ministry of Commerce (Available at: <http://www.cassava.org/doc/FactofThaiTapiocaStarch.pdf>. accessed: 23<sup>rd</sup> August 2009)

Qualification	Specification
Moisture (% maximum)	13.0
Starch (% minimum)	85.0
pH	5.0-7.0
Pulp (cm <sup>3</sup> maximum)	0.2
Ash (% maximum)	0.2
Fiber (% maximum)	0.3

Besides that, Silvestre (1987) found that starch is virtually pure carbohydrate. It is used for various purposes in food industries (sweetened products, thickeners, making tapioca, etc), paper manufacturing and other industries. The starch is produced in large factories, where the sequence of operations can be started by washing the tubers followed by peeling, grating, extracting the starch, washing the starch, refining and drying. Various procedures may be used to extract the starch and they are generally based on filtration and centrifugation (Industrial Studies and Surveys Division, 1980). Table 2.2a shows the comparison of starch gelatinization temperature range.

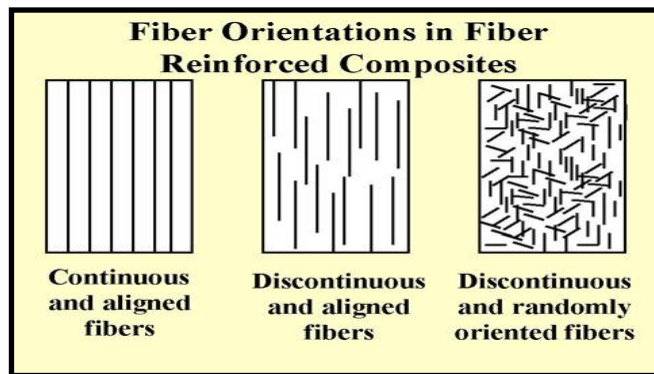
**Table 2.2a:** Comparison of starch gelatinization temperature range (Industrial Studies and Surveys Division, 1980)

Starch Gelatinization	Gelatinization Temperature Range [°C]
Potato	59-68
Tapioca	58.5-70
Corn	62-72
Waxy corn	63-72
Wheat	58-64

## Reinforcement

Filler for polymer composites have been variously classified as reinforcement's fillers or reinforcing fillers. Reinforcements are much stiffer and stronger than the polymer matrix and usually increase the modulus and strength of the fabricated composites. Thus, mechanical property modification may be considered as their primary function, although their presence may significantly affect thermal expansion, transparency, thermal stability and other final composites properties (Sgriecia, 2008).

For composites containing continuous reinforcements, mostly in thermosetting matrices, the long fiber or ribbons when pre-arranged in certain geometric patterns, may become as major component of the composite (they can constitute as much as 70% by volume in oriented composites). For discontinuous composites, the directional reinforcing agents (short fibers or flakes) are arranged in the composite in the different orientations and multiple geometric patterns, which are dictated by the selected processing and shaping methods, most often extrusion or injection molding show in the Figure 2.1a (Karina *et al.* 2007).



**Figure 2.1a:** Fiber orientation in fiber reinforced composites (Callister, 2003)

In certain cases, the content of the additive does not usually exceed 30-40% by volume. However, it should be noted that the manufacturing methods for continuous oriented fiber thermoplastic composites are available and amenable to much higher fiber contents, as used in high performance engineering polymers. The term reinforcement will be mostly used for long, continuous fibers or ribbons, whereas the term filler, performance filler or functional filler will mostly refer to short, discontinuous fibers, flakes, platelets or particulates (Bolton, 1998).

In general, the parameters' affecting the properties of polymer composites, whether continuous or discontinuous, includes (Duhovic *et al.* 2008):

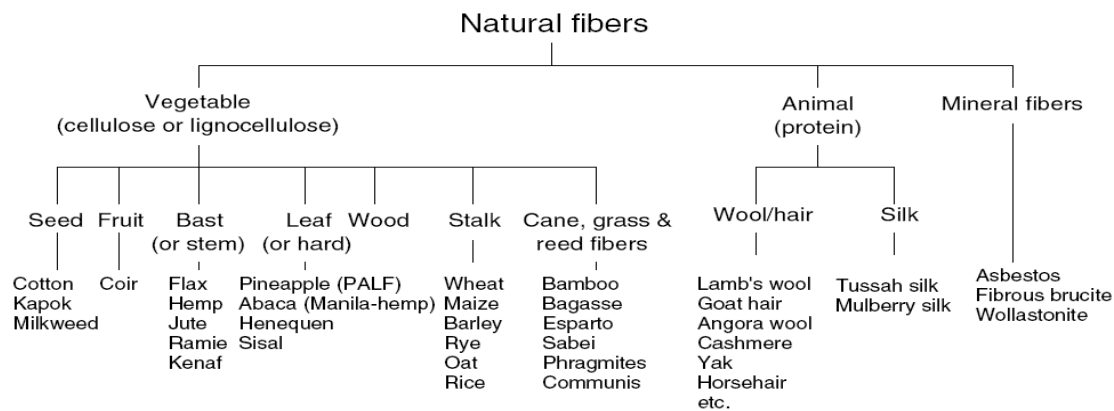
- i. The properties of additives (inherent properties, size and shape)
- ii. Composition of both element (matrix and reinforcement)
- iii. The interaction of components at the phase boundaries, which is also associated with the existence of a thick interface, known also as the interphase; this is often considered as a separate phase, controlling adhesion between the components
- iv. The method of fabrication

Bolton (1998) discussed that the fillers were considered as additives, which due to their unfavorable geometrical features. Surface area or surface chemical composition, could only moderately increase the modulus of the polymer, while strength (tensile and flexural) remained unchanged or even decreased. In addition, other major contribution of the filler was in lowering the cost of materials by replacing the more expensive polymer with other possible economic advantages. Faster molding cycles as a result of increased thermal conductivity and fewer rejected parts due to warpage are another advantage to be disclosed. Depending on the type of filler, other polymer properties could be affected; for example melt viscosity could be significantly increased through the incorporation of fibrous materials. On the other hand, the most common effect of most inorganic fillers is reduction in mold shrinkage and thermal expansion (Bolton, 1998).

### Natural Fiber

Karina *et al.* (2007) found that natural fiber filled polymer composites is a group of material that have natural fiber as filler component in the composites. Natural fibers were added into the composite to reinforce the fabricated composites. Examples of natural fiber are sugarcane, bamboo, wood, kenaf, cotton, coconut husk, oil palm, jute, areca fruit and many more. Fiber or fibers are a class of hair-like materials that are continuous filaments or in discrete elongated pieces, similar to pieces of thread. They can be spun into filaments, thread, or rope. They can also be used as a component of composite materials. They can also be matted into

sheets to make products such as paper or felt. Fibers can be categorized into two types that are natural fiber and non natural or synthetic fiber. Natural fibers include those made from plant, animal and mineral sources. Figure 2.2a shows the classification of natural fibers according to their origin.



**Figure 2.2a:** Classification of natural fibers (Duhovic, 2008)

Pickering (2008) explained that natural fibers such as flax, hemp, banana, sisal, oil palm and jute have a number of techno-economical and ecological advantages over the synthetic fibers such as glass fiber. The combination of interesting mechanical and physical properties together with their environmental friendly character has aroused interest in a number of industrial sectors, notably the automotive industry. The advantages and disadvantages of using natural fibers in composites are given in Table 2.3a.

**Table 2.3a:** Advantages and disadvantages of using natural fibers in composites (Sreekumar and Thomas, 2008)

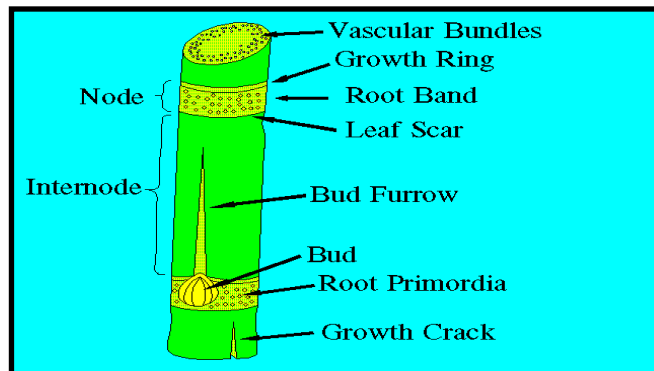
Advantages	Disadvantages
Low specific weight, compared with glass reinforced composites	Enormous variability
Renewable resource with production requiring low CO emissions	Poor moisture resistance
The processing atmosphere is worker-friendly with better working conditions	Poor fire resistance
High electrical resistance	Lower durability
Good thermal and acoustic insulating properties	Lack of fiber-matrix adhesion
Biodegradability	-

The main goals for the use of natural fibers in packaging are to provide additional stiffness and strength, minimize weight and reduce cost by lowering material content. In addition, when combining biodegradable materials with natural fiber like the sugar cane fiber cellulose, it will allow the biodegradability of the packaging material to be maintained (Duhovic *et al.* 2008). Table 2.4a shows the various properties of some natural fiber.

**Table 2.4a:** The various properties of some natural fiber (Cement & Concrete Institute, Midrand, 2001, 2008).

Fibre type	Coconut	Sisal	Sugar cane bagasse	Bamboo	Jute	Flax	Elephant grass	Water reed	Plantain	Mu-samba	Wood fibre (Kraft pulp)
Fibre length, mm	50 - 100	N/A	N/A	N/A	175 - 300	500	N/A	N/A	N/A	N/A	2,5 - 5,0
Fibre diameter, mm	0,1 - 0,4	N/A	0,2 - 0,4	0,05 - 0,4	0,1 - 0,2	N/A	N/A	N/A	N/A	N/A	0,025 - 0,075
Relative density	1,12 - 1,15	N/A	1,2 - 1,3	1,5	1,02 - 1,04	N/A	N/A	N/A	N/A	N/A	1,5
Modulus of elasticity, GPa	19 - 26	13 - 26	15 - 19	33 - 40	26 - 32	100	5	5	1,5	1,0	N/A
Ultimate tensile strength, MPa	120 - 200	275 - 570	180 - 290	350 - 500	250 - 350	1 000	180	70	90	80	700
Elongation at break, %	10 - 25	3 - 5	N/A	N/A	1,5 - 1,9	1,8 - 2,2	3,6	1,2	5,9	9,7	N/A
Water absorption, %	130 - 180	60 - 70	70 - 75	40 - 45	N/A	N/A	N/A	N/A	N/A	N/A	50 - 75

Sugarcane is a tropical grass native to Asia and is the product of interbreeding of four species of the *Saccharum* genus. Sugarcane has been identified as an essential world food source that has been used for hundred of years. Sugarcane is used primarily for sugar production. Bagasse is a by-product of sugarcane processing. Bagasse are contains of fibers, water and small quantities of soluble solids, mostly sugar. After being dried and crushed, the needle like fibers was found to resemble glass fiber (Patarau, 2005). The parts of fine sugarcane stalk from the stripped of their leaves are depicted as in the Figure 2.3a.



**Figure 2.3a:** Part of the stalk: stripped of leaves  
(Available at: <http://edis.ifas.ufl.edu/LyraEDIS>. accessed: 3<sup>rd</sup> August 2009)

In general, the present world production of sugarcane has reached 60 million tonnes level. Then, the quantities of these by-products produced yearly are approximately the following; the cane tops produced 200 million tones, the bagasse 60 million tones, filter mud is 5 million tones and molasses is 16 million tones (Patarau, 2005).

The sugarcane plant consist of a root system, slender leaves, and a tall talk that is composed of pith and rind fiber that are chemically identified as mostly cellulose, lignin, hemicellulose, and water. Both jute and sugarcane fiber consist of ultimate cells connected by binder such as lignin and hemicellulose to form the fiber bundles. The fiber bundles of jute and sugarcane are polygonal in shape and possess an opening, or lumen, in their centers. The ultimate cells exist in groups cemented together by binders known as hemicellulose and lignin (Patarau, 2005).

Recently, the bagasse is used mainly as fuel to generate steam in the sugarcane factories and a small friction to produce pulp and particle board (Patarau, 2005). The average composition of mill-run bagasse is shown in the Table 2.5a.

**Table 2.5a:** Bagasse chemical compositions (Chiparus, 2004)

Composition	Percentage (%)
Hemi-cellulose	30
Cellulose	50
Pentosan	30
Lignin	18

A sugar factory produces nearly 30 % of bagasse out of its total crushing. Many research efforts have attempted to use bagasse as a renewable feedstock for power generation and for the production of bio-based materials (Ahmad Nurhilmi, 2008). In this research, sugarcane bagasse will be fully utilized as potential natural filler reinforcement for the biocomposite application.

#### **Properties of Sugarcane Fiber Cellulose (SCFC)**

In this subtopic, the engineering properties of SCFC will be further investigated by referring to the past literatures review.

#### **Chemical Properties**

Pickering (2008) discussed the Chemical properties of SCFC are influenced by fiber growth time (day after planting), botanical classification of fibers and stalks height. Table 2.6a provides details on the comparison of the chemical composition in the total percentages between the SCFC and the other types of fiber.

**Table 2.6a:** Chemical composition of SCFC in comparison to the other fiber types (Pickering, 2008)

Type of fiber	Chemical composition (% total)				
	Cellulose	Lignin	Pentosan	Ash	Silica
Rice	28-48	12-16	23-28	15-20.0	9.0-14.0
Oat	31-48	14-19	27-38	6-8.0	4.0-6.5
Sugar	32-48	19-24	27-32	1.5-5.0	0.7-3.5
Bamboo	26-43	21-31	15-26	1.7-5.0	0.7
Kenaf	37-49	15-21	18-24	2.4	-
Jute	41-48	21-24	18-22	0.8	-
Coniferous	40-45	26-34	7-14	<1.0	-
Deciduous	38-49	23-30	19-26	<1.0	-
Abaca	56-63	7-9	15-17	3.0	-
Sisal	47-62	7-9	21-24	0.6-1.0	-

A notable physical difference between wood and non-wood fiber is that non wood fibers are formed in the aggregates or bundles. That is the reason why non-wood fibers like cotton and flax can be used to make rope and textile. The fibers aggregates are polymers, with a single fiber unit representing the basic building block of the polymer (Ahmad Nurhilmi, 2008).

#### **Physical Properties**

Physical properties like the fiber width and length are the important consideration for understanding the crystallinity and permeability of the fiber. Table 2.7a provides concise

comparison of characteristic of fine fiber length and width of some common types of the natural fiber (Pickering, 2008).

**Table 2.7a:** Physical characteristic for some common types of fiber (Pickering, 2008)

<b>Types of Fiber</b>	<b>Diameter (<math>\mu\text{m}</math>)</b>	<b>Length (mm)</b>	<b>Density (<math>\text{g/m}^3</math>)</b>
Ramie	60.0-250.0	11-80	1.44
Flax	9.0-70.0	5-38	1.38
Kenaf	2.0-6.0	14-33	1.20
Hemp	10.0-51.0	5-55	1.35
Bagasse	0.8-2.8	10-34	1.20

### **Mechanical Properties**

Pickering (2008) have mentioned that it is very difficult to present one comparison table that lists all the properties different of the fibers among various citation because of the use of different fibers, differing moisture conditions, and different testing methods. Many factors have influenced the mechanical properties of the natural fibers. Table 2.8a shows that there is a wide range of mechanical properties depending on the types of natural fibers. In general, bast fibers are the strongest.

**Table 2.8a:** Mechanical properties of some natural fibers (Pickering, 2008)

<b>Fiber</b>	<b>Elongation at break (%)</b>	<b>Tensile strength (MPa)</b>
Flax	1.2-3.0	343-1035
Ramie	2.0-4.0	400-938
Kenaf	2.7-6.9	295-930
Hemp	1.6-4.5	580-1110
Bagasse	0.9-1.0	20-290

### **Moisture Content**

Pickering (2008) stated a compilation of data on equilibrium moisture content (EMC) of different natural fibers at 65% relative humidity (RH) and 21°C as shown in the Table 2.9a.

**Table 2.9a:** Equilibrium moisture content (EMC) of different natural fibers (Pickering, 2008)

<b>Fiber</b>	<b>Equilibrium moisture content (%)</b>
Flax	7.0
Ramie	9.0
Hemp	9.0
Bagasse	28.7

### **Sieve Analysis**

In the research done by Ahmad Nurhilmi (2008), the sugarcane bagasse was blend to the small size and sieved to obtain the 150 micron of size fraction. This, to make sure it is free from the impurities. Because of that, the smaller particles sizes will gives very fine surface of the fabricated final product. The weight of bagasse was depended on the sieving duration. Table 2.10a shows the sieving duration and weight of sugarcane bagasse.

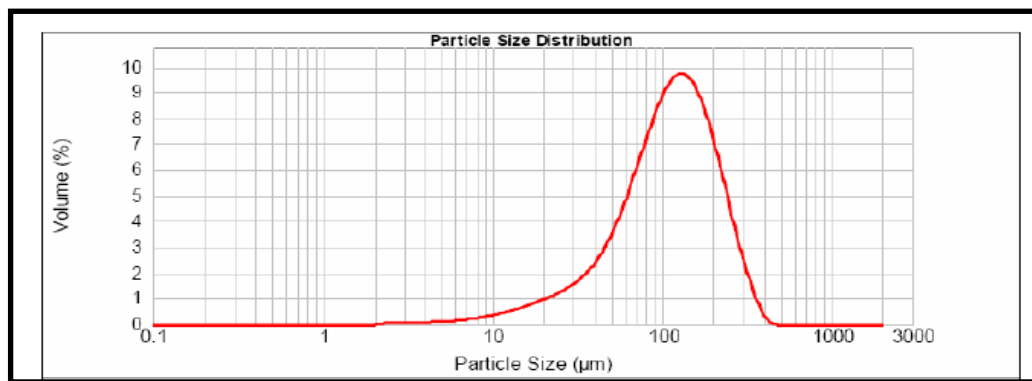


**Table 2.10a:** The sieve times and weight of bagasse (Ahmad Nurhilmi, 2008)

Time (minute)	Weight (g)
5	7.86
10	8.80
15	9.01
20	10.64
30	14.72

### Particles Size Analysis

Figure 2.4a shows the result of particles size distribution for sugarcane bagasse. Size distribution was in the range of 50 micron to 200 micron after sieved. The high volume percentage of the sugarcane bagasse particles size was at the 150 micron. Recently, the result showed, the smaller the particles size, the better quality of the final product produced. It was due to the lack of porosities which caused more particles interface connection and to make sure the bagasse is free from the impurities (Ahmad Nurhilmi, 2008).

**Figure 2.4a:** Particle size distribution (Ahmad Nurhilmi, 2008)

Previously, the lack of an alternative energy for the electricity with the storage capability for the use in off-season has been an unsolvable problem. A subject of research in several countries around the world today is to find a solution to sugarcane residues as energy sources such as in Cuba. Bagasse was burned as a means of solid waste disposal. However, corresponding to the rise of the oil price, bagasse has become recognized as an important residue derived fuel. The ultimate analysis of sugarcane bagasse, sugar cane agricultural residues (SCAR) and other main sugarcane residues is shown in Table 2.11a (Ahmad Nurhilmi, 2008).

**Table 2.11a:** Sugar cane residues ultimate analysis (Ahmad Nurhilmi, 2008)

Sugarcane residue	Ultimate analysis % dry matter					
	Carbon	Hydrogen	Oxygen	Nitrogen	Sulphur	Ash
Bagasse	47.40	7.20	40.69	0.00	0	4.71
Bagasse board dust	27.06	5.10	56.26	0.14	0	5.44
SCAR	46.00	6.60	41.70	0.00	0	5.65
Powdered cellulose	42.46	6.73	50.00	0.00	0	0.83

## Glycerol as plasticizer

Glycerol is the common name of the organic compound whose chemical structure is HOCH<sub>2</sub>-CHOHCH<sub>2</sub>OH. Propane-1,2,3-triol or glycerin (USP), consists of a chain of three carbon atoms with each of the end carbon atoms bonded to two [hydrogen](#) atoms (C-H) and a hydroxyl group (-OH) and the central carbon atom is bonded to a hydrogen atom (C-H) and a hydroxyl group (-OH). Glycerol is a trihydric [alcohol](#). This is because it contains three hydroxyl or alcohol groups. Glycerin is a thick liquid with a sweet taste that is found in fats and oils and is the primary triglyceride found in coconut and olive oil. It was discovered in 1779; when the Swedish chemist Carl Wilhelm Scheele (1742-1786) washed glycerol out of a heated a mixture of [lead](#) oxide (PbO) and olive oil. Today, it is obtained as a by product from the manufacture of soaps (Available at: <http://science.jrank.org>. accessed: 27<sup>th</sup> March 2010).

One important property of glycerol or glycerin is that it is not poisonous to humans. Therefore it is used in foods, syrups, ointments, medicines, and cosmetics. Glycerol is thick syrup that is used as the "body" too many types of syrup, for example, cough medicines and lotions used to treat [ear](#) infections. It is also an additive in vanilla extracts and other food flavorings. Glycerol is also added to [ice](#) cream to improve the texture, and its sweet taste decreases the amount of sugar needed. In the manufacture of foods, drugs, and cosmetics, oil cannot be employed as a lubricant because it might come in contact with the products and contaminate them. Therefore, the nontoxic glycerol is used to reduce [friction](#) in pumps and bearings (Available at: <http://science.jrank.org>. accessed: 27<sup>th</sup> March 2010).

## General Properties of Glycerol

The general information about the glycerol as depicted in the Table 2.12a.

**Table 2.12a:** General information of glycerol

(Available at: <http://www.jtbaker.com/msds>. accessed: 28 January 2010).

Property	Identification
Chemical name	1,2,3-propanetriol; glycerin; glycol alcohol; glycerol, anhydrous
Molecular Weight	92.10
Chemical Formula	C <sub>3</sub> H <sub>8</sub> O <sub>3</sub>

## Physical Properties of Glycerol

The physical properties of glycerol will be summarized by referring to the material safety data sheet (Available at: <http://www.jtbaker.com/msds>. accessed: 28 January 2010).

**Table 2.13a:** Physical properties of glycerol (Available at:

<http://www.dow.com/glycerine/products/optim.htm>. accessed: 27 March 2010)

Physical properties	Specifications
Melting Point	18°C
Critical temperature	492.2°C
Critical pressure	42.5 atm
Specific Gravity at 25°C	1.26201
Density at g/cc <sup>3</sup> , 25°C	1.25802
Molecular weight	92.09 g/mol
Solubility	Miscible in water
pH	Neutral to litmus
Odor	Odorless
Appearance	Clear oily liquid

### **Stability and Reactivity Properties of Glycerol**

By referring to <http://www.jtbaker.com/msds>, it found that glycerol is generally regarded as a safe material for which no special handling precautions are required. However, it is flammable. It is also oily in nature and may cause slipping hazard if spilled on the floor. Glycerol can be stable under ordinary conditions but it is very sensitive when involved in a fire because the toxic gases and vapors may be released and it will decomposed upon heating above 290°C and forming corrosive gas which known as acrolein. Glycerol can be classified as hazardous decomposition products. It is strong oxidizers which can react violently with acetic anhydride, calcium oxychloride, chromium oxides and alkali metal hydrides.

### **Ecological Information**

When released into soil and water, this material is expected to readily biodegradable and is not evaporate significantly. It is difference when released into the air. This is because this material may be moderately degraded by reaction with photochemically produced hydroxyl radicals and removed from the atmosphere to a moderate extent by wet deposition. For the environmental toxicity, this material is not expected to be toxic to aquatic life (Available at: <http://www.jtbaker.com/msds>, accessed: 28 January 2010).

### **Packaging Food Container**

Since 2003, the gap between the conventional petroleum-based plastics and biodegradable plastic prices has narrowed considerably due to the price jump of crude oil and energy as well as growing of biodegradable polymer production capacities (Dukalska, *et al.* 2008). Han (2005) mentioned that the plastic packaging has initiated two challenges: its dependence on petroleum and the problem of waste disposal. Most of today's conventional synthetic polymers are produced from the petrochemicals and are definitely not biodegradable. Stable polymers are the significant source of the environmental pollution, harming organic nature when they are dispersed in the environment. The raw materials such as fossil fuel and gas could be partially replaced by greener agricultural sources, which could also participate to the reduction of CO<sub>2</sub> emissions (Narayan, 2001).

Over the past five years, packaging suppliers have been introducing various forms of biodegradable plastics. These materials are made from a variety of plants (Dukalska *et al.* 2008). The market of biodegradable polymers at the present is growing based on the considerations that consumers and recycling regulations will drive demand for environmentally-friendly packaging. Some of the biodegradable polymers are already competitive alternatives to conventional food packaging. Polylactate (PLA) is being one of the most important biodegradable food packaging (Haugard and Martensen, 2003).

Renewable resource based biopolymers such as starch and PLA account for around 85% of the total production capacity with the synthetic biopolymers accounting for the remaining 15%. Biodegradable polymers market introduction has started successfully all over Europe (Platt, 2006). The shares of the three material classes: synthetic biodegradable, biobased biodegradable and biobased non-biodegradable are expected to change significantly towards biobased non-biodegradable bioplastics. Their share is about 12% in 2007 of a total production capacity of 26 2000 tones. It is expected that, in 2011 the share of biobased non biodegradable plastics will be almost 40% of the total capacity (Dukalska *et al.* 2008).

Dukalska *et al.* (2008) stated that the most important application sectors of biodegradable polymers at the present time are mainly for organically produced foods packaging, conventional fruit and vegetables as well as bread and bakery products, ready-to-eat foods, service packaging, shopping bags, catering products, bio waste bags and horticulture auxiliaries. Nets, trays and flow pack from PLA, cellulose and starch materials are being used as well. Not only the range of biodegradable products has widened but the number of those manufacturers, distributors and users has also increased. At present, PLA is the most widely used biodegradable polymer for fresh-food applications.

A new study from Pira International Limited, estimated that biodegradable packaging will grow at a compound annual growth rate (CAGR) of 22% by the introduction of lower-cost polyhydroxyalkanoate (PHA) in 2011. Until today the poor barrier properties of uncoated biodegradable materials have prevented their use for products requiring a long shelf life. Currently Hycail Finland have developed a new generation of biodegradable PLA material – Hycail ® XM 10204, which is ovenable and microwavable and can withstand temperatures over 200°C. Compostable PLA trays to improve shelf life for meats and other food products were developed by absorbing any liquids extruded during their storage. Biodegradable lidding film Alcan's CERAMIS®-PLA with high-barrier properties to seal food trays (for fresh meat, sausages, cheese and pasta packaging) has been introduced. Presently, biopackaging can be found in almost everywhere on the shelves in European supermarkets (Dukalska *et al.* 2008).

### **Processing of Composites**

According to Duhovic *et al.* (2008), the main issues that related with the processing of any composites utilizing the natural fibers are thermal instability, inhomogeneous quality and their hydrophilic nature. Biopolymers with melting temperatures below 200°C must be selected to minimize the fiber degradation. Various methods of preparing natural fiber biopolymer composites have been researched. To the great extent, fiber length will determine the methodologies available for the composites processing. However, the general methods used are sheet forming or compression molding, extrusion, injection molding and filament winding (Callister, 2003).

Long fibers may be used compression molded to maintain the fiber lengths. However, fiber abrasion is significant in most extrusion and compounding processes which often precede injection molding. In order to optimize the fiber dispersion, there is often some form of the preliminary mixing required before the final processing of the specimens. Both of the matrix and reinforcement will be compounded with the internal mixer. However, the lack of compatibility between both of the materials often caused by the differences in the polarity. Fiber and matrix modifications are often used with success to improve the dispersion and fiber matrix adhesion (Duhovic *et al.* 2008). In this research, the composites fabrication method that will be used is compression molding

### **Rules of Mixtures (RoM)**

The characteristics properties for the individual constituents of a composite are interact in various ways. This is to produce the collective properties of behavior of the composites. Some properties obey the rules of mixtures (RoM) because the composites properties are the weighted sums of the values of the individual constituents. In other words, properties are a function of the amounts and the distribution of the contributing material. In some composites, the properties of the components are somewhat independent and supplement each other to produce a collective performance by the composites (Jacobs and Kilduff, 2001). Thus, all the important parameter like density and volume of material are the important consideration for modulus of elasticity determination by using the RoM.

### **Density**

The density is the value of each constituents in the composites  $f_1, f_2, \dots, f_n$  where  $f$  is referred to fiber. As for laminated composites, the rule of mixtures always predicts the density of fiber reinforced composites as shown in the Equation 2.1 where the subscripts  $m$  and  $f$  refer to the matrix and fiber.

$$\rho_c = \rho_m * V_m + \rho_f * V_f \quad (2.1)$$

where,

$\rho_c, \rho_m, \rho_f$  – densities of the composite, matrix and dispersed phase respectively

$V_m, V_f$  – volume fraction of the matrix and dispersed phase respectively